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Patents for tomorrow's plastics

Global innovation trends in recycling, circular design and alternative sources
Key Findings | October 2021

Executive summary

Our heavy reliance on single-use plastics (SUPs) has long been of growing concern. The COVID-19 pandemic triggered a massive deployment of masks, gloves, disposable test kits, swabs, syringes and medical packaging – all made from SUPs. This is just one of many instances illustrating the tension between the social benefits of plastics and the pollution that they cause.

Over the past 70 years, plastics have become an essential material for many industries and indeed for the economy. However, there is growing awareness of the dire environmental cost of this economic success. Today, the bulk of plastic production ends up as waste dumped in the environment, posing a critical and often immediate threat for countless endangered species, ecosystems and dependent socio-economic systems all over the planet.

The systemic challenge raised by this environmental crisis lies at the heart of the EU Green Deal (European Commission EC, 2019) and of the United Nations (UN) 2030 Sustainable Development Goals. To cope with the growing volume of plastic produced, used and dumped in today's linear economy, the plastics industry has to transition into a fully circular model, where end-of-life plastic products are not discarded as waste but instead become a source of value creation.

Innovation, regulation and international collaboration are needed to enable this transition. Progress in technologies related to waste recovery and transformation is crucial to support the systematic recycling of plastic waste and to maximise the value derived from it. Dominant technologies in the plastics industry often reflect a linear-economy focus on performance and durability. Nevertheless, further innovation in alternative plastics and designs can also foster the reusability, recyclability and biodegradability of plastic products, or even eliminate the need for plastic usage.

Aim of the study

Aimed at decision-makers in both the private and public sectors, this report is a unique source of intelligence on these technologies and the technical problems they aim to address. The report draws on the latest patent information available and the expertise of European Patent Office (EPO) examiners to provide a comprehensive analysis of the innovation trends driving the transition towards a circular economy for plastics.

Patent information provides robust statistical evidence of technical progress. The data presented in this report shows trends in high-value inventions for which patent protection has been sought in more than one country. (IPFs [1]). It highlights technology fields that are gathering momentum and the crossfertilisation taking place. Trends in circular plastic innovation have never been more important to the sector's development. Therefore, it provides a guide for policymakers and decisionmakers to direct resources towards promising technologies, assess their comparative advantage at different stages of the value chain and shed light on innovative companies and institutions that may be in a position to contribute to long-term sustainable growth.

1 Each international patent family (IPF) covers a single invention and includes patent applications filed and published at several patent offices. It is a reliable proxy for inventive activity because it provides a degree of control for patent quality by only representing inventions for which the inventor considers the value sufficient to seek protection internationally. The patent trend data presented in this report refer to numbers of IPFs.

Key findings

The US and Europe stand out as global innovators for a circular plastics industry

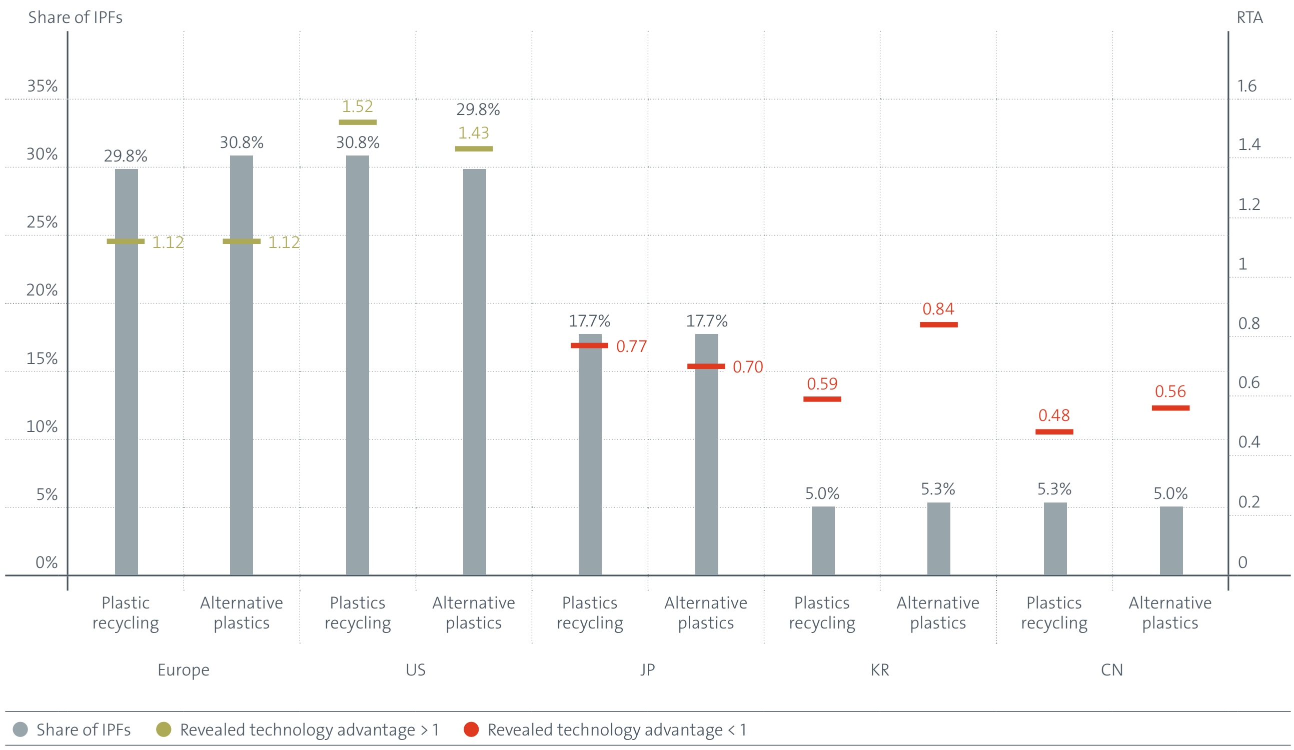
The US and Europe [2] are by far the main global innovators in terms of efforts to make the plastics industry circular, with about 30% each of IPFs related to the circular plastics industry between 2010 and 2019.[3] They are also the only major innovation centres truly specialising in these technologies. The US, in particular, shows significantly higher revealed technological advantages in both plastic recycling and bioplastic technologies.[4]

With about 18% of IPFs in 2010–2019, Japan is far ahead of the Republic of Korea and the People's Republic of China (each at about 5%). However, all three show a similar lack of specialisation in these technologies.

Within Europe, France, the UK, Italy, the Netherlands and Belgium stand out for their specialisation in both plastic recycling and bioplastic technologies. Although it posted the highest share of IPFs due to its larger economy, Germany lacks specialisation in these fields.

Figure E.1

Origins of inventions related to the circular plastics industry, 2010-2019



Source: European Patent Office

2 Unless specified otherwise, Europe and European countries refer in the study to all the 38 contracting states of the European Patent Convention (EPC). These countries include but are not restricted to the 27 member states of the European Union (EU).

3 The date attributed to a given IPF always refers to the year of the earliest publication within the IPF.

4 Specialisation is measured here using the revealed technological advantage (RTA) index. The RTA indicates a country's specialisation in terms of circular plastics innovation relative to its overall innovation capacity. It is defined as a country's share of IPFs in a particular field of technology divided by the country's share of IPFs in all fields of technology. An RTA above one reflects a country's specialisation in a given technology. Only the highest RTAs (approximately 1.5 or more) are reported in the chart.

Chemical and biological recycling generated the highest level of patenting activities

Mechanical recycling is currently the simplest and most commonly used solution to transform plastic waste into new products. It generated nearly 4 500 IPFs from 2010 to 2019, with an increasing focus on addressing the quality degradation issues when recycling plastic waste that is collected post consumer. However, with more than 9 000 IPFs over the same period, it is chemical and biological recycling methods that stand out in terms of the number of IPFs.

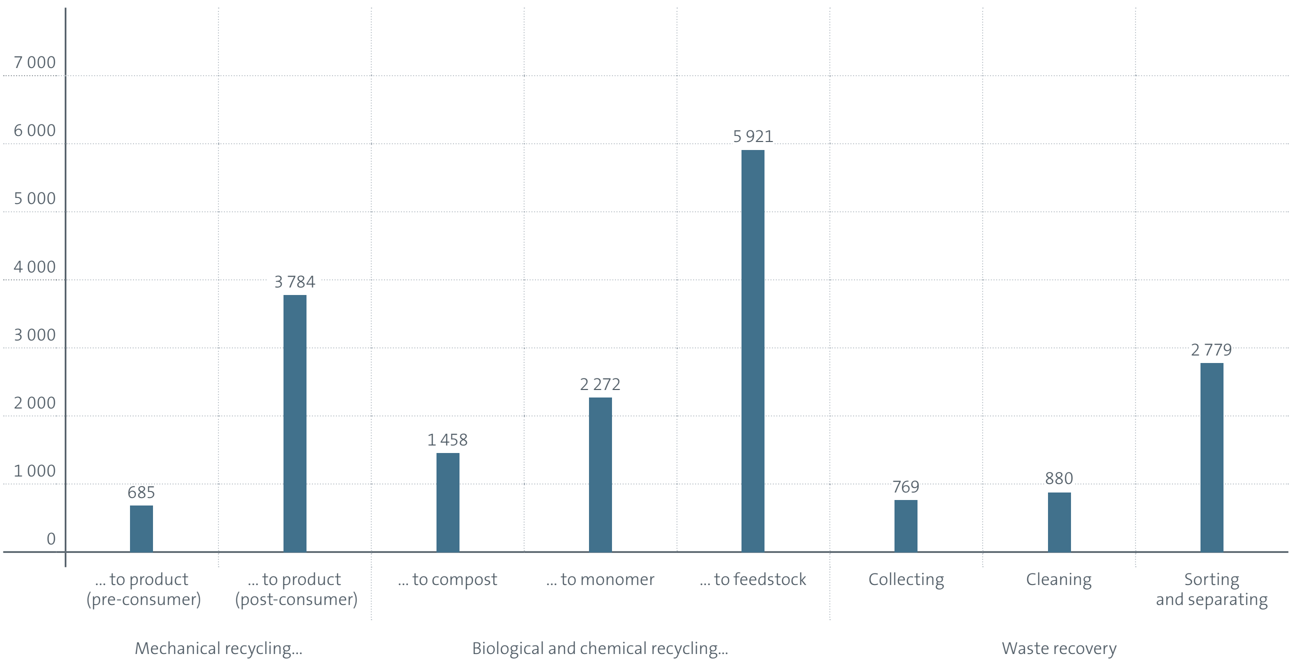
Chemical methods mainly consist of energy-intensive plastic-to-feedstock recycling processes (such as cracking and pyrolysis). Here, the chemical structure of plastic waste is converted into a mixture of basic chemicals, allowing for flexible reuse in the petrochemical industry.

However, innovation in these technologies reached a peak in 2014. Emerging plastic-to-monomer recycling technologies now offer possibilities to break down polymers into their original building blocks, allowing for near virgin-quality material and a larger number of possible cycles. Likewise, recent biological plastic-to-compost recycling represents a comparatively small number of IPFs. This promising technology involves the use of living organisms to degrade polymers into compost.

All these methods require an effective recovery of plastic waste (about 3 400 IPFs from 2010 to 2019), where different categories of plastics are identified, separated and cleaned before recycling. Innovation efforts are mainly focused on the sorting and separating of waste, including the use of sophisticated technologies such as optical recognition and artificial intelligence (AI).

Figure E.2

Innovation in recycling technologies (number of IPFs, 2010-2019)



Note: Some inventions may be relevant to different technology fields, resulting in the related IPFs being counted once in each field.

Source: European Patent Office

Fundamental research is key to further progress in chemical and biological recycling. Europe's good performance in this respect shows potential to bring new technologies to market.

Chemical and biological recycling methods rely far more on upstream fundamental research than other recycling technologies, with nearly 20% of IPFs stemming from universities and public research organisations (PROs) in the period 2010 to 2019. Innovation in waste recovery and plastic-to-product recycling frequently relies on available technologies and existing engineering approaches, which explains the lower shares (7.4% and 6.8%, respectively) of IPFs produced by research institutions in these fields.

European countries and the US demonstrate a clear lead with chemical and biological recycling methods, each with 29% of the IPFs stemming from research institutions. Europe is the only major innovation centre that contributes more to IPFs in upstream research than to all IPFs in the field (26%). By contrast, the US's and Japan's contributions to upstream IPFs (29% and 11%) are lower than their respective shares in all IPFs (36% and 17%).

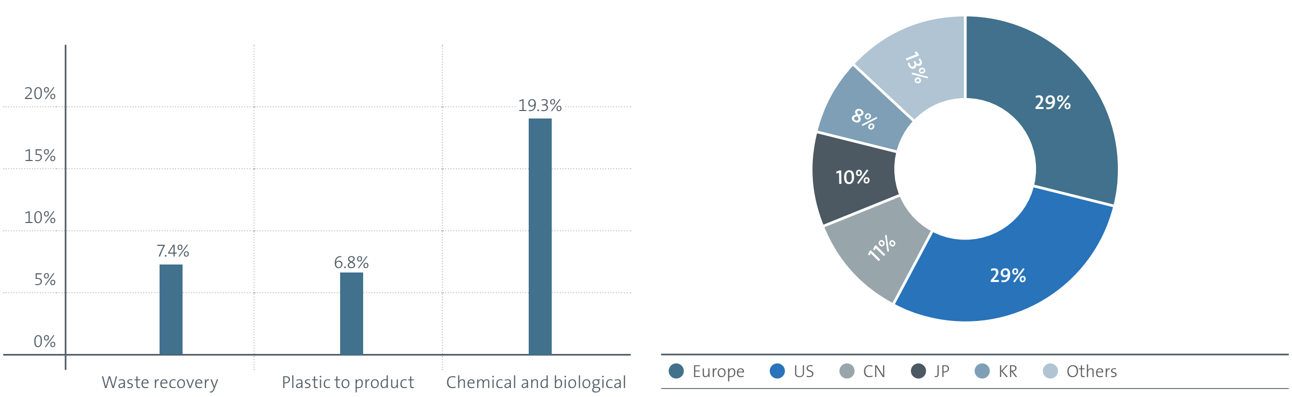
This suggests that Europe, despite being particularly active in fundamental research, is not exploiting its full potential when it comes to transferring these technologies to industry. A closer analysis of the IPFs originating from start-up and scale-up companies supports this finding. Although the number of such IPFs increased in the same proportions in both regions between 2010 and 2019, US start-ups and scale-ups generated four times as many IPFs than their European counterparts (338 versus 84) over the decade.

Figure E.3

Upstream research in recycling technologies, 2010–2019

a) Share of IPFs generated by universities and PROs

b) IPFs generated by universities and PROs in chemical and biological recycling



Note: The geographic origins of the IPFs in Figure E.3b are based on the country of the applicants.

Source: European Patent Office

Bioplastics provide alternatives to conventional fossil raw materials

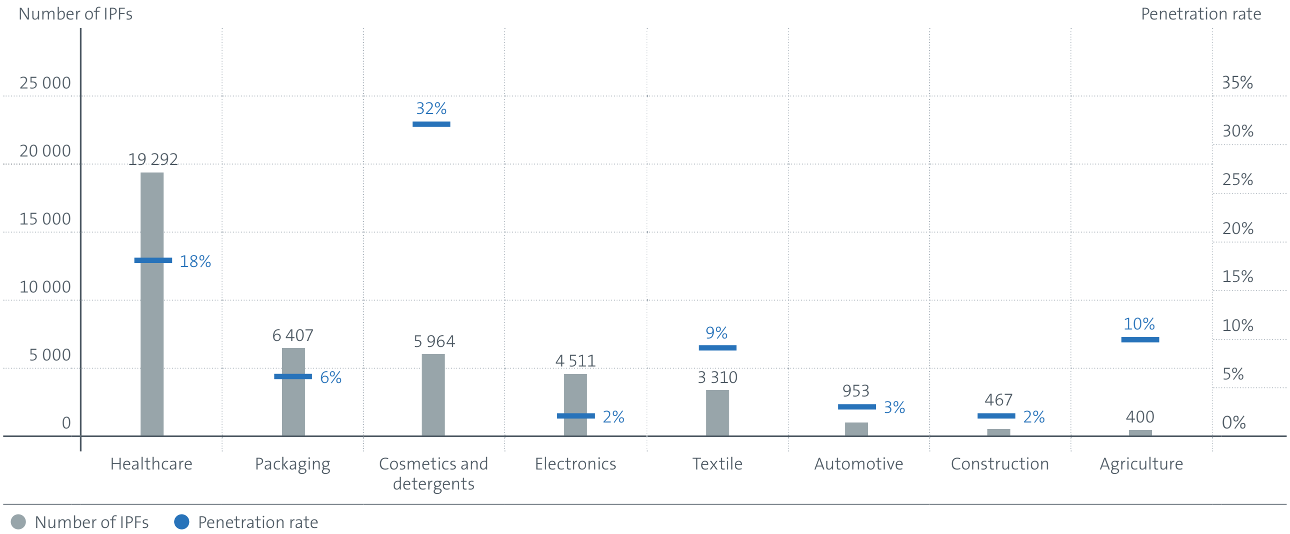
Bio-based and/or biodegradable plastics show potential for enhancing circularity and reducing the carbon emissions generated by the use of conventional fossil raw materials. Patenting activities in these bioplastics took off in the late 1980s and since then have followed a growth trend similar to that of conventional plastics technologies.

Of these materials, chemically modified natural polymers (such as modified cellulose) generated the largest share of patenting activities over the past decade. However, polymers from bio-sourced monomers have been the fastest-growing field. Most of the patents in this field relate to so-called “drop-in plastics” (i.e. Bio-PE, Bio-PET) which, although not biodegradable, allow for a reduced consumption of non-renewable resources and CO_2 emissions at the production stage. Among the smaller fields, industrial natural polymers show potential for creating reusable, recyclable plastics that can be readily broken down by microorganisms.

Despite accounting for less than 3% of the total demand for plastics in Europe (PlasticsEurope, 2020), healthcare is by far the most important industry in terms of the number of IPFs in bioplastics, with more than 19 000 IPFs recorded from 2010 to 2019. Meanwhile, cosmetics and detergents show the highest rate of innovation in bioplastics. In that sector, IPFs related to bioplastics are at 32% of the level of IPFs for conventional plastics. Packaging, electronics and textiles are also significant contributors to innovation in bioplastics, with 6 400, 4 500 and 3 300 IPFs, respectively, from 2010 to 2019. Agriculture shows a high penetration rate (10%) and posted 2.5 times more IPFs for bioplastics in 2019 than in 2010.

Figure E.4

Innovation in bioplastics for selected sectors



Note: The penetration rate is defined as the ratio of the number of IPFs in alternative plastics to the number of IPFs related to conventional plastics in the same sector.

Source: European Patent Office

Rapidly emerging technologies allow for novel designs of durable plastic materials

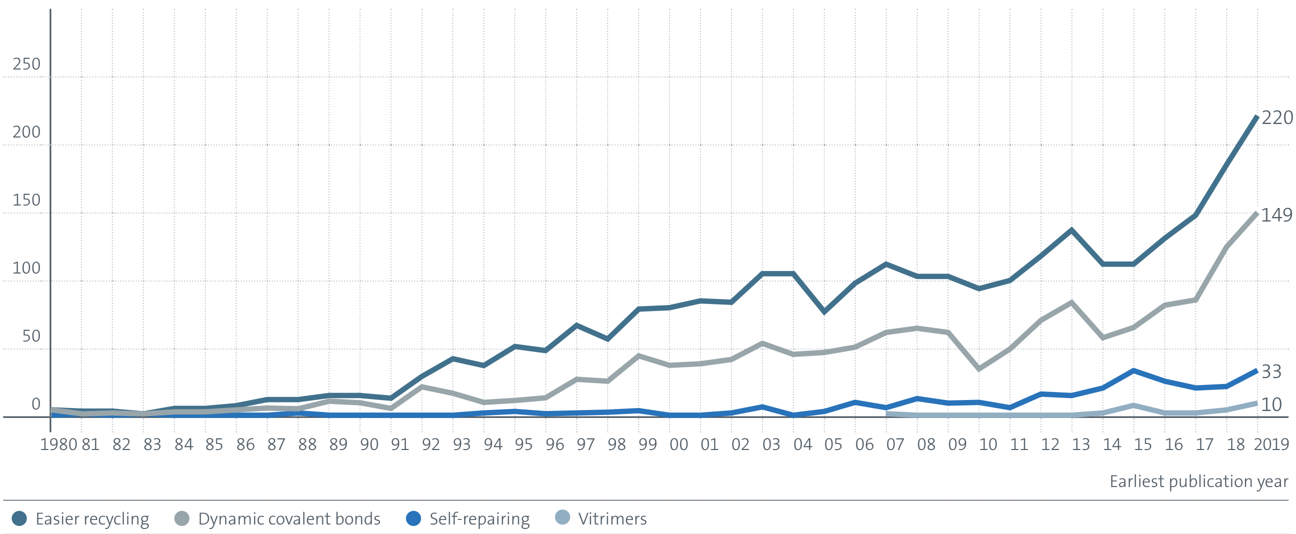
In the early 1990s, technologies focused on plastic design for easier recycling started to emerge and these have been developing exponentially ever since. The rapid growth of patenting in these fields is driven by progress in dynamic covalent bonding, a synthetic strategy employed to form 3D networks of macromolecular chains that can break and reform via reversible chemical reactions. This dynamic reversibility can overcome difficulties encountered in the processing and recycling of the many polymers used in aerospace, construction, transport and microelectronics.

Among recent developments, vitrimers are a promising type of covalent adaptable network (CAN). Vitrimers are strong, stable and intrinsically self-healing, with potential for replacing thermoset plastics in high-performance and lightweight applications, such as the production of composite parts for aircraft, automotive, sports equipment and wind turbine blades.

Japan demonstrates a strong lead in technologies using dynamic covalent bonds, with nearly half (49%) of related IPFs from 2010 to 2019. The US follows with 24%, while European countries contribute only 17%. However, most of the IPFs originating from universities and PROs are from European and US research institutions (40% and 30%, respectively), while Japan has only 7%. Japan leads overall despite a small presence in university research, in stark contrast to Europe, which contributes nearly twice as much to upstream university research than to related patenting activities.

Figure E.5

IPFs related to design for easier recycling, dynamic covalent bonds, self-repairing polymers and vitrimers, 1980-2019



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